Faculty of Engineering

EFFECT OF STUB ON THE PERFORMANCE OF 3-DB BRANCH LINE COUPLER FOR LOW-COST VECTOR NETWORK ANALYZER APPLICATION

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ARLIZ BINTI ABDUL SAMAT

A final year project report submitted in partial fulfilment of
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ABSTRACT

High Frequency (HF) technology is very important and common. With the high-speed telecommunications and wireless technology that is rapidly increasing, it is very important for electrical and electronics engineers to understand the basic Radio Frequency (RF) applications and then apply the knowledge in designing advanced RF applications in future. To assist the engineers and designers in achieving this goal, High Frequency Test Instrument is very important. One of the most useful test equipment for RF designers is Vector Network Analyzer. Unfortunately, the price of single VNA is very expensive and cost hundred thousand of Ringgit Malaysia. Thus, low cost VNA can be developed to reduce the cost needed to test the instruments in microwave. One of the way to develop low cost VNA is by producing microstrip design for the components inside the VNA especially the coupler. By integrating all of the components to build up the VNA into microstrip design, the cost of the VNA can be reduced effectively. Branch line coupler is commonly used due to its simplicity. Reducing the size of the coupler can provide cheaper fabrication and more space can be utilized for performance improvement. However, the great drawbacks of microstrip coupler is its narrow bandwidth which makes it unable to cater the high frequency of the VNA. Thus, to overcome the narrow bandwidth, stub will be implemented into the 3-dB microstrip branch line coupler design to improve the bandwidth performance. Few analysis of stub implementations have been done in this research project in order to investigate the effect of the different stubs' designs towards the bandwidth improvement of the microstrip coupler. Based on the analysis, by implementing two stubs with width and length of 1 mm, positioned at location 0, which is at the centre of the microstrip coupler, shows best result with return loss of -57.98 dB and bandwidth has been improved from 1.09 GH z to 1.39 GHz compare to the conventional branch line coupler which is improved by 30.36%.

ABSTRAK

Dalam era teknologi maklumat, teknologi Frekuensi Tinggi merupakan satu teknologi yang sangat penting. Dengan adanya teknologi telekomunikasi berkelajuan tinggi dan tanpa wayar yang kian pesat membangun, ianya sangat penting bagi jurutera elektrik dan elektronik untuk memahami aplikasi radio frekuensi (RF). Setelah memahami aplikasi tersebut, pengetahuan dalam merekabentuk aplikasi RF hendaklah diterapkan untuk masa akan datang. Untuk membantu jurutera dan pereka dalam mencapai matlamat ini, instrumen ujian frekeunsi tinggi sangat penting. Salah satu peralatan ujian yang paling berguna untuk pereka RF ialah Penganalisis Rangkaian Vektor atau lebih dikenali sebagai Vector Network Analyzer (VNA). Malangnya, harga VNA adalah sangat mahal dan bernilai beratus ribu Ringgit Malaysia. Oleh itu, VNA kos rendah boleh direka untuk mengurangkan kos yang diperlukan untuk menguji instrumen dalam gelombang mikro. Salah satu cara untuk membina VNA kos rendah adalah dengan menghasilkan reka bentuk microstrip untuk komponen di dalam VNA. Contohnya, pengganding mikrostrip. Pengganding mikrostrip yang bersaiz kecil boleh mengurangkan kos VNA dengan berkesan. Dengan mengurangkan saiz pengganding, fabrikasi komponen yang lebih murah dan lebih banyak ruang boleh digunakan sekaligus meningkatkan prestasi komponen. Walau bagaimanapun, semakin kecil pengganding mikrostrip, semakin terhad jalur lebar bagi komponen tersebut. Hal ini akan menyebabkan komponen tersebut tidak dapat beroperasi dalam frekuensi yang tinggi. Oleh itu, untuk mengatasi masalah jalur lebar yang terhad, teknik penambahan kaki pengganding akan diimplementasikan ke dalam reka bentuk pengganding mikrostrip 3-dB untuk meningkatkan prestasi jalur lebar. Beberapa analisis pelaksanaan teknik penambahan kaki pengganding telah dilakukan di dalam projek penyelidikan ini untuk mengkaji kesan reka bentuk kaki pengganding yang berlainan ke arah penambahbaikan jalur lebar penyambung mikrostrip. Berdasarkan analisis, dengan meletakkan dua kaki pengganding dengan lebar dan panjang 1 mm serta posisi pada lokasi 0, iaitu di tengah pengganding mikrostrip, ianya menunjukkan hasil terbaik dengan kehilangan kembali -57.98 dB dan jalur lebar telah ditingkatkan dari 1.09 GHz ke 1.39 GHz berbanding pengganding konvensional yang bertambah baik sebanyak 30.36%.

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LIST OF SYMBOLS

S-parameter	-	Scattering-parameter
S_{11}	-	Scattering-parameter from port 1 reflected back
S_{22}	-	Scattering-parameter from port 2 reflected back
S_{12}	-	Scattering-parameter from port 1 to port 2
S_{21}	-	Scattering-parameter from port 2 to port 1
P_1	-	Port 1
P_2	-	Port 2
P_3	-	Port 3
P_4	-	Port 4
Δ, α	-	Difference
Z_0	-	Initial impedance
λ	-	Wavelength
$\lambda/4$	-	Quarter-wavelength
Z_s, Z_T	-	Characteristic Impedance
Z_a, Z_b	-	Shunt branch line impedance
ε_r	-	Dielectric constant
GHz	-	Giga Hertz
mm	-	millimeter
Ω	-	Ohm
C	-	Coupling value
λ_f	-	Operating frequency wavelength
c	-	Speed of light
f_0	-	Operating frequency

w_p	-	Microstrip patch width
w_h	-	Microstrip height
π	-	Pi
ln	-	Natural algorithm
θ	-	Electrical length
$\pm$	-	More or less
T_a	-	Z_a matrices
T_b	-	Z_b matrices
A_e, B_e, C_e, D_e	-	ABCD-parameter for even mode
Γ	-	Reflection coefficient
T	-	Transmission coefficient

LIST OF ABBREVIATIONS

HF	-	High Frequency
RF	-	Radio Frequency
WLAN	-	Wireless LAN
VNA	-	Vector Network Analyzer
SNA	-	Scalar Network Analyzer
NA	-	Network Analyzer
FYP1	-	Final Year Project 1
FYP2	-	Final Year Project 2
DGS	-	Defected Ground Structure
LTCC	-	Low Temperature Co-Fired Ceramic
CST	-	Computer Simulation Technology

CHAPTER 1

INTRODUCTION

1.1 Background of Research

High Frequency (HF) technology is very important and common. Each of us become a society that is dependent on communication device, which are linked to peripheral devices by using wireless LAN (WLAN) and Bluetooth, and latterly the communication network [1]. All these modern technologies are close related to HF technology.

The implementation of the complete transmission link from the transmitter module via the sender and receiver antenna to the receiver plays a significant role. With the high-speed telecommunications and wireless technology that is rapidly increasing, it is very important for electrical and electronics engineers to understand the basic Radio Frequency (RF) applications and then apply the knowledge in designing advanced RF applications in future.

As we can see, many successful products require numerous of designs and these designs were aimed to optimize the functions of the products. The networks which needed to provide high-speed communication also require antenna designs to be maximized in its efficiency and minimize the size and cost. To assist the engineers and designers in achieving this goal, High Frequency Test Instrument is very important.

One of the most useful devices for RF designers and engineers is Network Analyzer. There are two types of Network Analyzer available which is Network Analyzer (SNA) and Vector Network Analyzer (VNA). These two Network Analyzer measure different components. SNA measures phase component of the transmission and reflection parameters of the circuit under test. Meanwhile VNA measures magnitude and phase components equivalently [2].

Figure 1.1 shows the R&S®ZVA Vector Network Analyzer. This analyser have 2 to 4 ports with the frequency range up to 110 GHz [3]. It has high measurement throughput with ergonomic user interface and error-free calibration. This VNA is the first VNA with IF bandwidths up to 30 MHz for pulsed measurements on amplifiers and mixers.

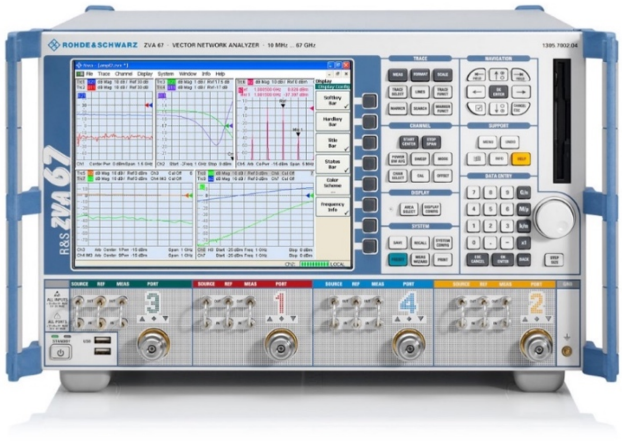

Figure 1.1: R&S®ZVA Vector Network Analyzer [1]

Based from Figure 1.1, the VNA measured both magnitude and phase of the components. Therefore, it used scattering parameters (S-parameters). S-parameters is used to measure four properties of a two-port circuit. In a complete VNA, it consists of two measurement sections. One measurement section is the forward direction. This direction measures S_{21} (forward gain and phase) and S_{11} (input reflection magnitude and phase). The other measurement section is the reverse direction. This direction measures S_{22} (output reflection magnitude and phase) and S_{12} (reverse gain and phase, also known as reverse isolation) [3].

Therefore, the VNA is quite a bit more complicated compare to SNA [4]. VNAs are very expensive device. A single VNA can cost about tens of thousands of Ringgit Malaysia [5] and due to the expensive developments of VNA, low cost NA’s development was very popular since 1990’s. The first fabricated low-cost NA was designed in 1999 by Lambrecht with very limited features [6], operating from 50 kHz to 200 MHz and it consider partially complete NA.

Then, in 2009, Thomas designed a low-cost RF NA [7] and it was considered the most complete low-cost NA. Figure 1.2 shows the top view of Thomas’s VNA board with the measurement of 100 x 60 mm^2. This VNA covered frequency range from 1 kHz to 1.3 GHz and the power for this VNA can be supplied from a computer USB interface.

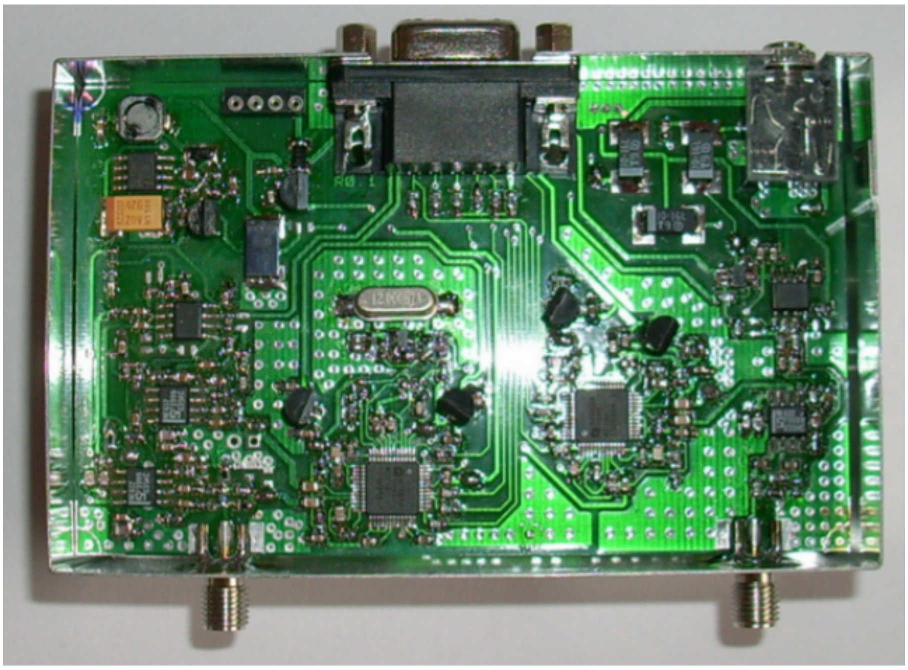

Figure 1.2: Top view of Thomas's VNA board [7]

Figure 1.3 is the block diagram of the low-cost VNA measurement device. The VNA consists of microwave components such as directional coupler, quadrature frequency synthesizer, a reflection measurement circuit, a transmission measurement circuit, a pair of phase and magnitude RF detectors, a multi-channel analog-to-digital converter (ADC), and a specialized USB- aware microprocessor. Although this device considered as the most complete low cost VNA, the design had a few shortcomings where, the operating range is only covers between 1 kHz and 1.3 GHz due to the limitations in operating frequency for some RF components, such as frequency generator, directional coupler and RF power detector at that time [8].

One of the most important components in VNA is directional coupler. Directional coupler is a device that acts as the heart of the VNA [9]. It consists of two coupled transmission lines. If the energy goes through the main port in one direction and not in the opposite direction, these transmission lines will be arranged to couple energy to an auxiliary.

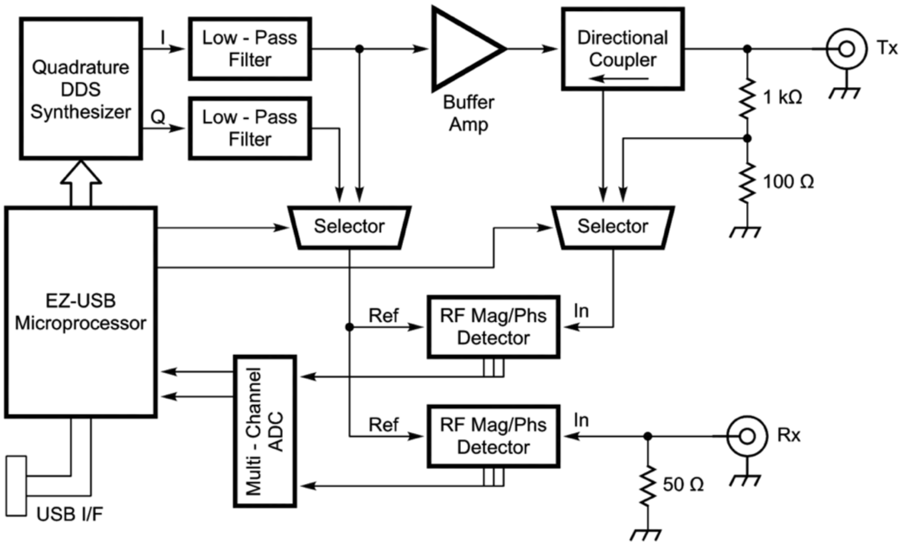

Figure 1.3: Block diagram of the Vector Network Analyzer [9]

However, due to the expensive cost of VNAs, one can develop a low cost VNA by integrating all of the components into microstrip technique. Microstrip design consists of dielectric substrate on one side and the other side is ground plane. The advantages of microstrip design is it is smaller size, low fabrication cost and capable of supporting multiple frequency bands. However, the drawback of this design is the bandwidth is narrow and it consume too much unnecessary space in between the branch line [10]. Till this date, many researchers have done researches on ways to tackle the microstrip problem such as multilayer technique, addition of multiple branches and also stub technique.

Therefore, this thesis will focus on one of the techniques that have been mentioned which is stub technique. Investigation on the effect of stub technique towards the performance of the conventional coupler especially on the bandwidth is done to observe at what degree of improvement does the technique can offer.

1.2 Problem Statement

Vector Network Analyzer is the most useful test instruments for RF and microwave designers. Unfortunately, the price of single VNA is very expensive and cost hundred thousand of Ringgit Malaysia. Thus, low cost VNA can be developed to reduce the cost needed to test the instruments in microwave. One of the ways to develop a low cost VNA is by producing microstrip design for the components inside the VNA. For example, microstrip coupler.

By integrating all of the components to build up the VNA into microstrip design, the cost of the VNA can be reduced effectively. Branch line coupler is commonly used due to its simplicity. Reducing the size of the coupler can provide cheaper fabrication and more space can be utilized for performance improvement. However, the great drawback of microstrip coupler is its narrow bandwidth which makes it unable to cater the high frequency of the VNA. Thus, to overcome the narrow bandwidth, stub technique will be implemented into the 3-dB microstrip branch line coupler design to improve the bandwidth performance. Few analysis of stub technique implementations will be done in this research project in order to investigate the effect of the different stubs' designs towards the bandwidth improvement of the microstrip coupler in order to observe at what degree of improvement does the technique can offer.

1.3 Objectives

The objectives for this research are stated as follows:

i. To investigate on the conventional microstrip 3-dB branch line coupler design and operation.
ii. To design a 3-dB branch line coupler that will be operated at 10 GHz on the microstrip implementation to maintain the low cost.
iii. To analyze the effect of the stub technique towards the performance of the 3-dB branch line coupler.

1.4 Scope of Research

The scope of research for this project is to design and investigate the operation of a conventional microstrip 3-dB branch line coupler. Then, once completed, a 3-dB branch line coupler that operated at 10 GHz will be designed. The software that is used in this project is Computer Simulation Technology (CST) Microwave Studio. After that, few analyses in implementing stub technique into the 3-dB branch line coupler will be done to observe its effect towards the bandwidth performance. Once the design and the simulation of the coupler is done, the characteristics of the coupler is observed. The characteristics include the return loss, isolation loss, throughput, coupling and phase difference between output ports. Lastly, the comparison between the conventional branch line coupler with the improved design will be done to verify the bandwidth performance.

1.5 Thesis Outlines

This thesis is divided into five chapters; Introduction, Literature Review, Methodology, Result and Conclusion. Chapter 1 presents the introduction and background of the research that will be explained briefly. This includes brief elaboration on the project, problem statement, objectives and the scope of research.

Chapter 2 presents literature review on the NA, application of NA, basic concept of VNA and components in VNA, basic concept of branch line coupler and the techniques that had been used by other researchers.

Chapter 3 presents the methodologies of the research that will be explained through the flow chart, Gantt chart and design specification. The techniques and calculation to design the microstrip 3-dB branch line coupler used in this project will also be explained briefly.

The results of the research will be discussed in Chapter 4. All the designs and parameters will be shown in the form of comparison. The most suitable coupler will be chosen based on the length, width, position and the number of stubs in the stub technique implementation.

Lastly, in Chapter 5, which is the conclusion, the bandwidth of the couplers in the term of the percentage will be shown. Apart from that, the comparison of the new design and the conventional branch line coupler will be done. This chapter will be discussed more on the future work that can be done to improve the research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review on Network Analyzer, application of Network Analyzer, Vector Network Analyzer, basic concept and components in the Vector Network Analyzer will be introduced in this chapter. Also, types of coupler such as branch line coupler, coupled-line coupler and Lange coupler will be discussed. Besides that, the techniques to improve the performance of coupler will also be concluded in this chapter which includes stub technique, addition of branch line technique, multilayer technique, Low Temperature Co-Fired Ceramic (LTCC) technique and Defected Ground Structure technique.

2.2 Network Analyzer

Network Analyzer is a device that is used to measure the network parameters in electrical networks. Commonly, network analyzer is used to measure S-parameters as the electrical networks such as reflection and transmission. This is due to the network analyser can easily measure at high frequencies. Apart from that, network analyzers are also used to characterize two-port networks for amplifiers and filters.

Network analyzer can be categorized into two types, Scalar Network Analyzers (SNA) and Vector Network Analyzer (VNA). The SNA is only can be used to measure the magnitude, where the VNA measure the phase shifts. SNA also is easy to implement however it does not give adequate information concerning system response unless the purpose for measurement was concerned with amplitude effects on the signal [11]. Therefore, VNA supersede SNA as network analyser. Unfortunately, the VNA is more complex and more expensive as it covers a large frequency range.

2.3 Application of Network Analyzer

Vector Network Analyzer (VNA) is very useful in measuring and analyzing the S-parameters of high frequency circuits such as reflection and transmission coefficients. The reflections of the waves start to matter when the frequency is high enough and distributed effects need to be taken.

Ideally, antenna would radiate all the energy it received. Then, antennas will reflect some of the energy back to the source. It will only radiate the received energy at certain frequencies. With the use of VNA, the amount of energy reflected can be measured effectively. Amplifiers in the VNA will reflect some energy from both input and output. This will increase the amount of gain.

As mentioned before, commercially available VNAs are very expensive equipment, costing tens of thousands of Ringgit Malaysia. Table 2.1 shows the example of low-cost VNA that had been develop since 1990's. However, there are still some drawbacks in their design features.